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Optical Emission Spectroscopy of Carbon Arc Discharge Plasma

Kashif Chaudhary[a,b*], Usman Tariq[a], Sufi Roslan[b], Ong Shude[a], M. S. Aziz[a]

[a]Laser Center, Ibnu Sina Institute for Scientific and Industrial Research (ISI-SIR), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Physics Department, Faculty of Science, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

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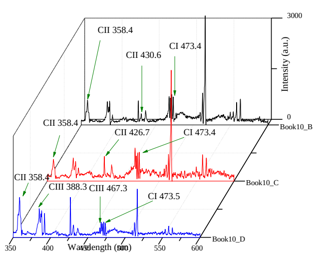
*Corresponding author
kashif@utm.my

Graphical abstract



Abstract

The arc discharge plasma is one of the efficient technique to fabricate nano-structures such as nanotubes, nanoparticles and thin films, which have variety of technological applications. In this study, plasma dynamics such as the electron density and temperature for arc discharge carbon plasma in methane ambient environment is presented to investigate the impact and contribution of physical parameter as arc current and ambient pressure on the plasma dynamics. The electron temperature and density is estimated applying in situ optical emission spectroscopy. The optical spectra are recorded for applied arc current 50A, 60A, 70A, 80A and 90A for ambient pressures 100torr, 300torr and 500torr. A rise in electron temperature and electron density is detected with increase in applied arc current and ambient pressure. The obtained results reveal that in arc discharge process, the arc current and ambient pressure have significant contribution towards the kinetics of the plasma species.

Keywords: Arc discharge plasma, optical emission, electron temperature & density

Abstrak

Plasma nyahcas arka, adalah salah satu teknik yang berkesan untuk menghasilkan struktur-struktur nano seperti tiub nano, zarah nano dan saput nipis, yang mempunyai pelbagai aplikasi teknologi. Dalam kajian ini, dinamik plasma seperti ketumpatan elektron dan suhu untuk plasma karbon nyahcas arka dalam metana persekitaran khas dibentangkan untuk menyiasat kesan dan sumbangan parameter fizikal sebagai arus arka, arka tekanan khas pada dinamik plasma. Suhu dan kepadatan elektron dianggarkan memberi spektroskopi pelepasan optik posisi asal. Spektrum optik direkodkan untuk arus arka gunaan 50A, 60A, 70A, 80A dan 90A untuk tekanan khas 100torr, 300torr dan 500torr. Kenaikan suhu elektron dan ketumpatan elektron dikesan dengan peningkatan dalam arus gunaan arka dan tekanan khas. Keputusan yang diperolehi menunjukkan bahawa dalam proses nyahcas arka, arus arka dan tekanan khas mempunyai penglibatan signifikan ke arah kinetik pada spesies plasma.

Kata kunci: Plasma nyahcas arka, pelepasan optic, suhu & ketumpatan elektron

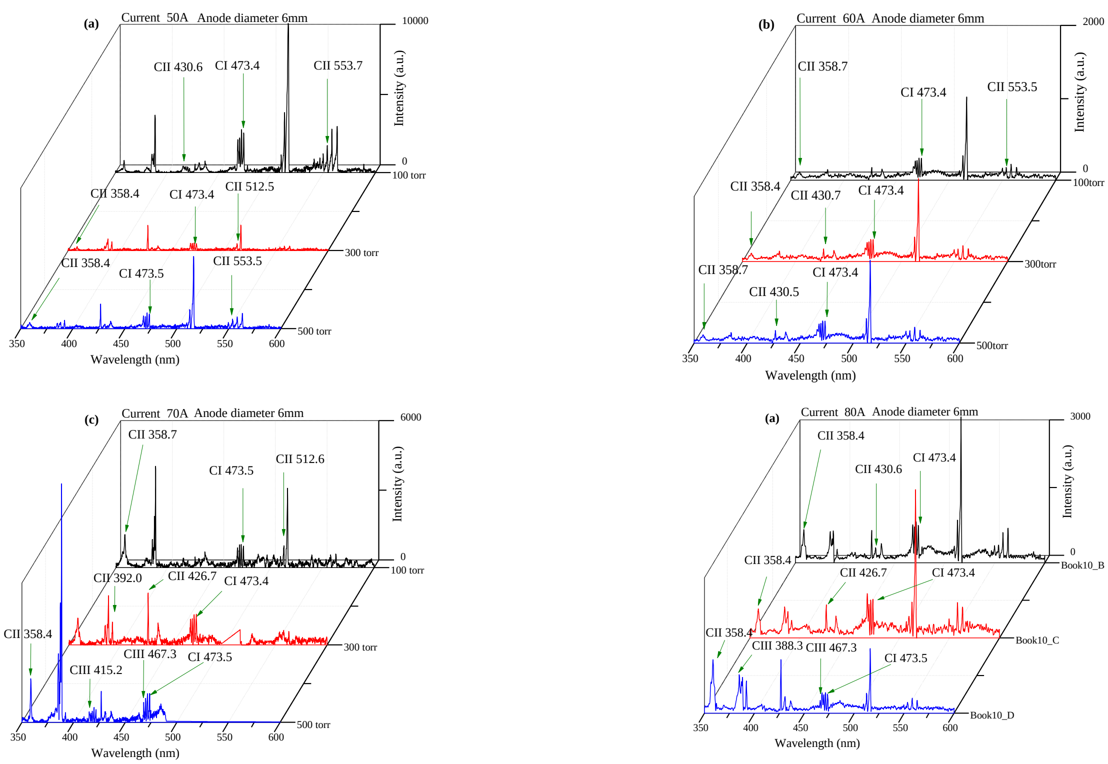
1.0 INTRODUCTION

The thermal plasmas are employed extensively in various applications as surface modification, sputtering, etching, micro and nano fabrication, thin film deposition, ion implantation, waste and toxic materials treatment, bio-material compatibility, metal cutting, welding and as source of particles and radiations (ions, electrons, excited atoms, radicle, molecules, x-rays, etc.) [1-3]. The carbon arc discharge plasma is one of the simplest and efficient method capable to grow carbon nano-structures and thin films which have numerous technological applications. A high influx and temperature of plasma species plays vital role in the development of nano structures and thin films. To optimize the growth of nanostructures effectively, the understanding contribution of different physical parameters towards the plasma characteristics is of great importance [4, 5].

In present work, arc discharge plasma is produced between two cylindrical graphite electrodes under controlled ambient conditions with methane as background gas. The dynamics of plasma as electron temperature and density are estimated for different input powers and ambient pressures by optical emission spectroscopy. The contribution of arc current and ambient pressure towards the kinetic of the plasma is observed and discussed.

2.0 EXPERIMENTAL

The arc discharge is produced in gap between two 4 N pure graphite cylindrical rods with diameter 11 mm as cathode and diameter 6 mm as anode. The methane gas is used as background gas. The optical emission spectra are captured by optical spectrometer (Ocean Optics HR4000) in optical range 300 nm to 700 nm. The plasma radiations are focused via bi-convex lens (of focal length f=15 cm) on the optical fiber with diameter 600 μm connected to the optical spectrometer. The optical spectrum for each experimental condition is recorded for 300ms integration time. The optical emission spectra are recorded for applied arc current 50 A, 60, 70 A, 80 A and 90 A for ambient pressures 100 torr, 300 torr, 500 torr.



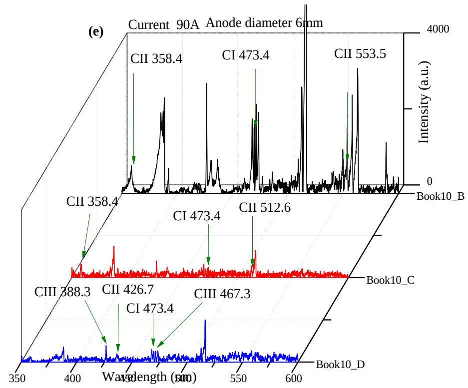


Figure 1 Optical emission spectra at pressure 100 torr, 300 torr and 500 torr I for arc current (a) 50 A, (b) 60 A, (c) 70 A, (d) 80 A & (e) 90 A

3.0 RESULTS AND DISCUSSION

Figure 1 (a to e) shows the optical emission spectra (OES) of carbon arc plasma at ambient pressure 100torr, 300torr and 500torr with for arc current 50 A, 60 A, 70 A, 80 A and 90 A respectively. The black color spectra correspond to the ambient pressure 100 torr, red colour spectra represents the ambient pressure 300 torr and blue colour spectra associated to the 500 torr ambient pressure. To calculate the plasma temperature and density, the spectral lines corresponding to neutral carbon (CI) atoms at 473.42 nm and 473.51 nm, singly ionized (CII) carbon ions at 358.4 nm, 358.7 nm, 426.7 nm, 430.6 nm, 392.0 nm, 392.2 nm, 512.5 nm, 512.6 nm, 553.5 nm and 553.7 nm, and doubly ionized (CIII) carbon ions at 388.3 nm, 415.2 nm and 467.3 nm from the recorded spectra are selected as labelled in Figure 1.

The plasma temperature and density are estimated using Boltzmann intensity ratio method and Saha equation respectively [6]. The measurements are performed under the special circumstances of local thermodynamic equilibrium (LTE), which is tested according to McWhirter's Criterion [7]. The numerical data related to higher level energies, degeneracy and transition probability values for selected emissions lines is taken from the National Institute Standard and Technology (NIST) database to calculate the plasma temperature [8].

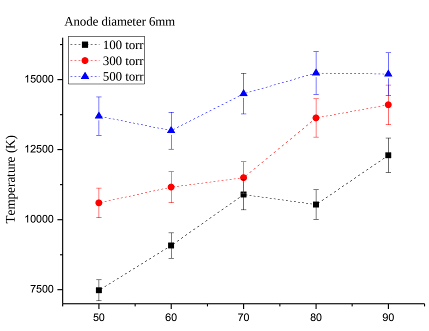


Figure 2 Plasma Temperature of arc plasma for arc current 50A, 60A, 70A, 80A & 90A at pressure 100torr, 300torr and 500 torr

Figure 2 shows the estimated values of plasma temperatures under different physical conditions An increase in plasma temperature with increase in arc current as well as ambient pressure is observer. The minimum plasma temperature 7480 K is estimated for arc current 50 A at pressure 100 torr, whereas maximum value 15200 K is measured for arc current 90 A at pressure 500 torr as shown Figure 2. Figure 3 illustrates an increasing trend of plasma density with increase in arc current as well as ambient pressure. The minimum plasma density is observed $8.93 \times 10^{12}/m^3$ for arc current 50 A at pressure 100 torr and maximum plasma density $5.61 \times 10^{23}/m^3$ is obtained for arc current 70 A at pressure 300 torr as depicted in Figure 3.

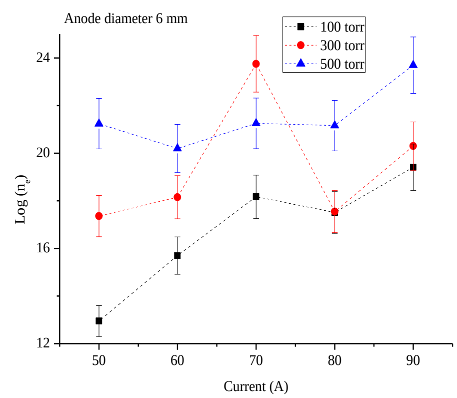


Figure 3 Density of arc plasma for arc current 50 A, 60 A, 70 A, 80 A & 90 A at pressure 100 torr, 300 torr and 500 torr

As a general trend, a linear increase in plasma temperature and plasma density is observed with increase in applied arc current as well as with increase in ambient pressures as shown in Figures 2 and 3. The estimated values of plasma temperatures and densities by atomic emission spectroscopy are in agreement with the values determined by the other researchers using different theoretical and experimental approaches [9, 10]. In plasma, energy flux at the anode surface is increased with increase in arc current which accelerate the rate of evaporation of particles carrying high energy. These higher energy carbon species evaporated from the anode surface contribute to increase the temperature and density of electrons in the plasma. The increase in ambient pressure changes the electron energy density function, which reduces the number of electrons carrying very high and very low energies and increases the number of electrons with average energies [11].

4.0 CONCLUSION

A linear increase in plasma temperature and density is observed with increase in applied arc current from 50 A to 90 A as well as increase in methane ambient pressure from 100 torr to 500 torr. The escalation in plasma temperature and density is observed higher for increase in ambient pressure as compared to increase in arc current.

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